

sensor decorated with single-stranded DNA, as shown in figure 1, might provide the needed specificity to serve as an array element.¹ They found that sensors made with different DNA strands did indeed show different responses, as measured by the nanotube's conductivity, to the same odorant chemicals. The sensors responded to the odorants within seconds, recovered their equilibrium conductivity when the odorant was removed, and maintained a reproducible response for dozens of cycles.

Now, the same researchers have turned their attention to the problem of telling the difference between very sim-

ilar molecules. They've found that with suitably chosen DNA sequences, they can create sensors that discriminate between organic molecules that differ by a single carbon atom, and even between molecules that are enantiomers, or mirror images, of each other.² Human noses can do that, but not many electronic sensors can.

Figure 2 shows one pair of enantiomers the researchers looked at, (+)-limonene and (–)-limonene. To us, one smells like lemon–orange; the other smells like sour orange and turpentine. In DNA–nanotube sensors made with one particular DNA sequence, conductivity

through the nanotube increased—by up to 40%—in the presence of (+)-limonene and decreased just as much in the presence of (–)-limonene. The same sensor could also distinguish, though less strongly, between the two enantiomers of carvone, one of which smells like spearmint and the other like caraway.

The researchers tested their sensors in the lab under carefully controlled conditions, with just one odorant in a stream of argon gas. But to be useful components of an electronic nose, sensors would have to operate in air under a range of atmospheric conditions—humidity, for example—and in the presence of background odors.

It's still not understood exactly how the DNA–nanotube sensors work. "But that's the case for essentially all chemical detection schemes based on nanostructure transistors," says Johnson. "It would be terrific if we could develop that understanding in the coming years, ideally to the point where we could model the responses quantitatively."

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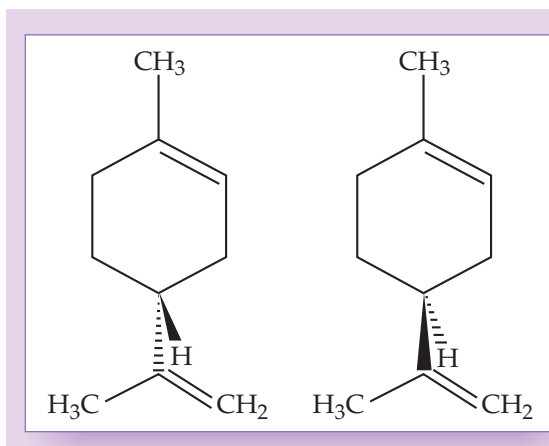


Figure 2. The two enantiomers, or mirror-image molecules, of limonene. Solid and dashed triangles represent chemical bonds that extend above and below the plane of the page, respectively. The human olfactory system can distinguish the two molecules; so can a nanotube sensor decorated with a suitably chosen strand of DNA.

References

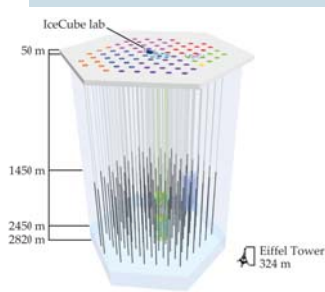
1. C. Staii et al., *Nano Lett.* **5**, 1774 (2005).
2. S. M. Khamis et al., *AIP Adv.* **2**, 022110 (2012).

physics update

These items, with supplementary material, first appeared at <http://www.physicstoday.org>.

IceCube fails to see neutrinos from gamma-ray bursts.

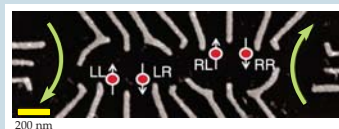
Cosmic-ray protons and nuclei with ultrahigh energies exceeding 10^{18} eV originate in powerful extragalactic accelerators; gamma-ray bursts (GRBs) are a well-studied possibility. From April 2008 to May 2010, even as the IceCube neutrino observatory was being constructed near the South Pole (see the article by Francis Halzen and Spencer Klein, *PHYSICS TODAY*, May 2008, page 29), it was already looking



for the neutrinos that would be produced by the interactions of ultra-high-energy protons with the intense photon field of a GRB. If GRBs were the source of all ultra-high-energy cosmic rays, the detector would have registered at least some neutrinos coming from the bursts—exactly how many is model dependent, but the most popular model gives 8.4. However, the IceCube team has announced it saw none. Evidently, they concluded, either GRBs are not the exclusive source of ultra-high-energy gamma rays, or some basic GRB physics has eluded our understanding. IceCube, shown in the

figure and now fully functional, contains 86 strings of photodetectors embedded deep in Antarctic ice. The detectors observe the Cherenkov radiation produced by energetic muons created by neutrino–ice interactions. Armed with a catalog of GRBs that exploded during their data runs—which used 40 and 59 strings of photodetectors—the IceCube team searched in vain for suitable muon tracks that coincided with a GRB and that pointed back to the burst. In addition to its continued search for GRB neutrinos, IceCube is looking for neutrinos from another class of impressive cosmic accelerator, active galactic nuclei. (R. Abbasi et al., IceCube collaboration, *Nature* **484**, 351, 2012.) —SKB

Entangled two-spin qubits. Individual spin states in quantum dots were one of the systems first proposed for implementing qubits for quantum computation. Among their



advantages are their potential for scalability and for miniaturization. But they are hard to control, and they can also quickly decohere and lose the information stored in their quantum states. In contrast, qubits built from pairs of spins in two adjacent quantum dots are much more easily controllable and more isolated from their environment. That isolation, though, makes it difficult for researchers to couple them—a critical step in any computation process. Now, Amir Yacoby and